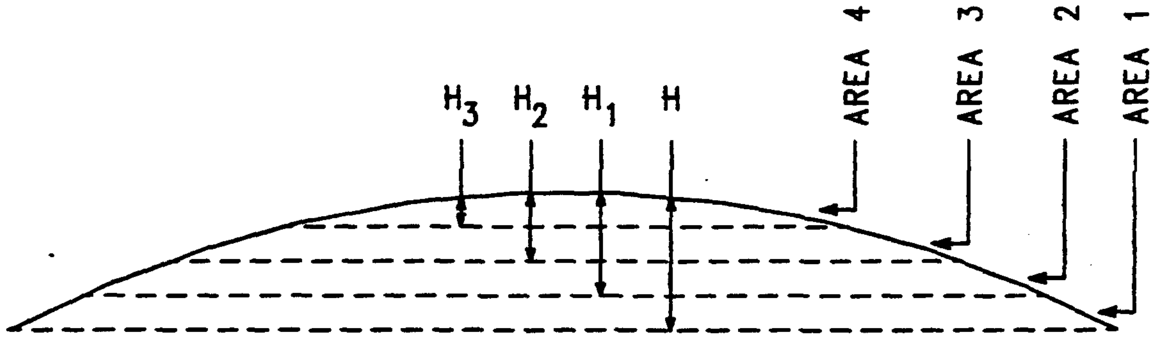
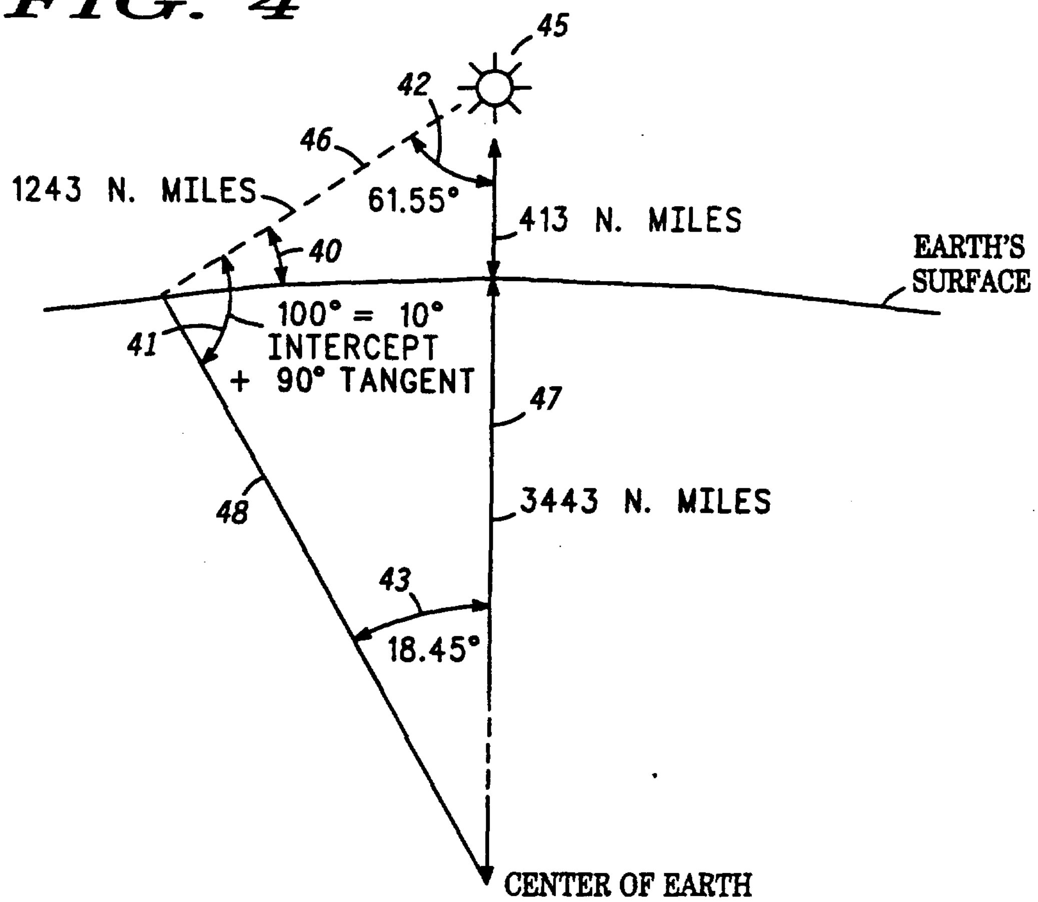

AREA 4
AREA 3
AREA 2
AREA 1
H_3
H_2
H_1
H

FIG. 3

FIG. 4


45
42
46
1243 N. MILES
61.55°
413 N. MILES
40
EARTH'S SURFACE
100° = 10° INTERCEPT + 90° TANGENT
41
47
48
3443 N. MILES
43
18.45°
CENTER OF EARTH

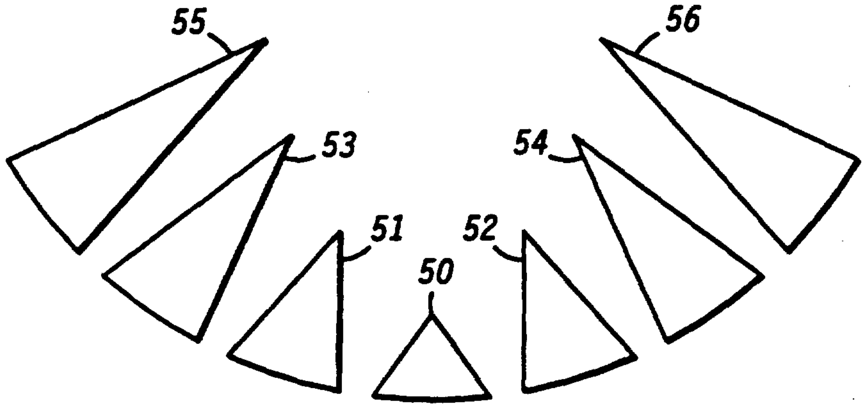
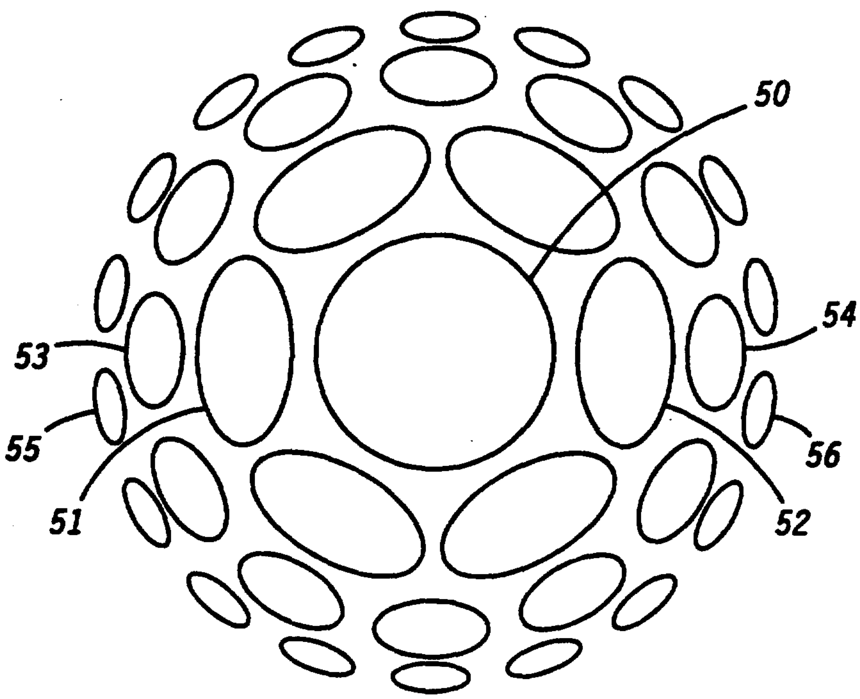


FIG. 5

FIG. 6



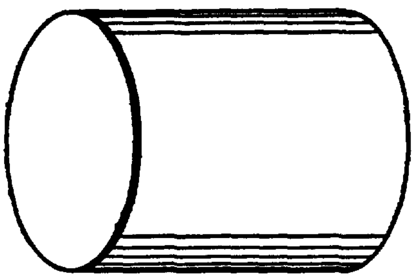


FIG. 7A

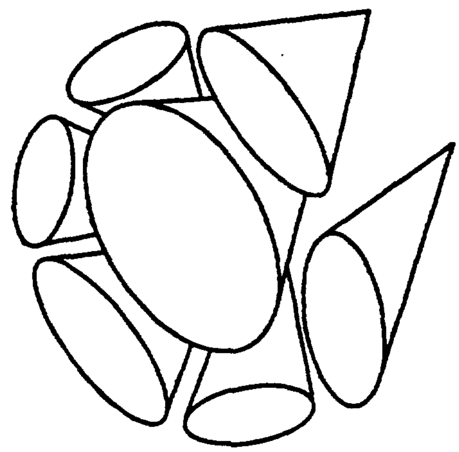


FIG. 7B

FIG. 7C

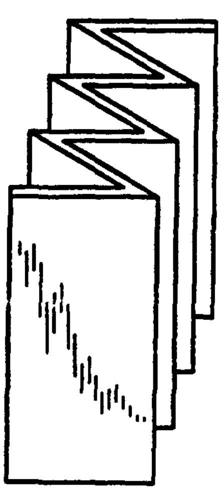
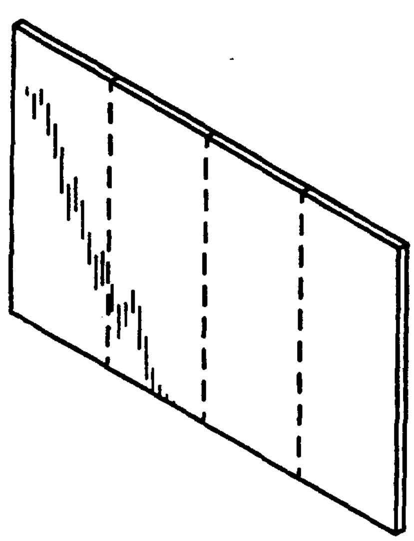


FIG. 7D



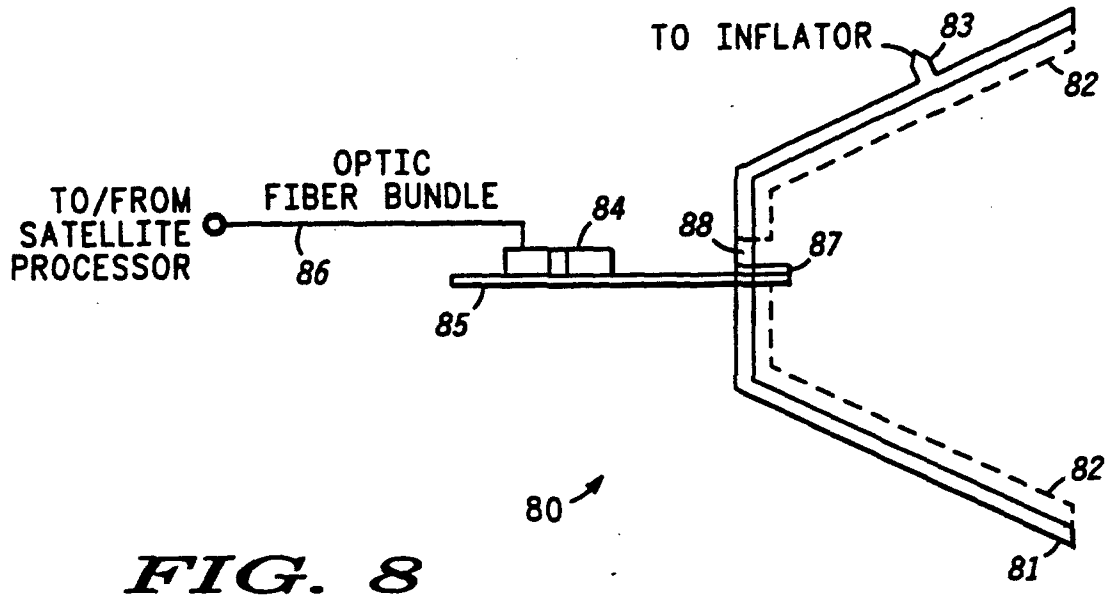
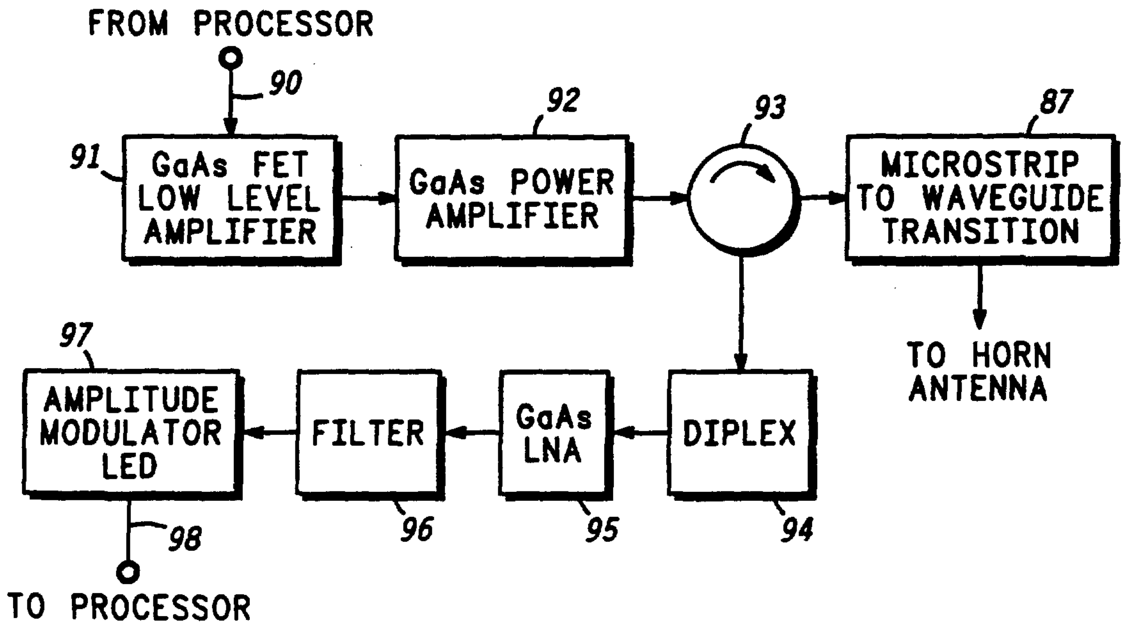

TO INFLATOR
83
82
OPTIC
FIBER BUNDLE
TO/FROM
SATELLITE
PROCESSOR
84
88
87
86
85
82
80
81

FIG. 8

FIG. 9


FROM PROCESSOR
90
92
93
87
91
GaAs FET
LOW LEVEL
AMPLIFIER
GaAs POWER
AMPLIFIER
MICROSTRIP
TO WAVEGUIDE
TRANSITION
TO HORN
ANTENNA
97
AMPLITUDE
MODULATOR
LED
FILTER
GaAs
LNA
DIPLEX
98
96
95
94
TO PROCESSOR

MULTIPLE BEAM DEPLOYABLE SPACE ANTENNA SYSTEM

This application is a continuation of prior application Ser. No. 415,814, filed Oct. 2, 1989, now abandoned.

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is related to copending U.S. patent applications Ser. Nos. 263,849; 402,743; 415,842; 415,815 and 414,494.

BACKGROUND OF THE INVENTION

The present invention pertains to antenna systems for spacecraft and more particularly to a deployable antenna array system which projects a multiple beam pattern with each beam covering a disjoint area.

Spacecraft typically achieve communications (i.e. "uplinks" and "downlinks") with earth-based stations by projecting spot beams to certain areas. These earth-base systems may include but are not limited to land-based stations, water-based stations, such as those located on ships, stations based on airplanes or other spacecraft. The spot beams which are projected by spacecraft may be relatively narrow or broad beams. Small beams are easily focused upon a known earth-based source. For communication situations in which many sources are randomly located over a portion of the earth, that entire portion of the earth must be covered by the antenna system.

For communication by the satellite with a number of earth-based stations, a limited number of communications frequencies or channels exist. Spatial diversity between satellite antenna beams is required. Therefore, satellite communication with a plurality of earth stations is limited to the number of antenna beams (or cells) projected by the antenna system. As cell numbers are increased, spatial diversity becomes difficult to maintain.

In addition, a large number of satellite antennas is difficult to launch into space. Furthermore, large numbers of antennas are difficult to position and deploy in space once the launching vehicle has achieved proper orbit.

Accordingly, it is an object of the present invention to provide uniformly sized spot beams for facilitating communications between satellites and a plurality of earthbased stations.

SUMMARY OF THE INVENTION

In accomplishing the object of the present invention, a novel multiple beam deployable space antenna system is shown.

A multiple beam space antenna system facilitates communications between a satellite and a plurality of earth stations. The multiple beam space antenna system has a plurality of antennas which are disposed in a spherical configuration. Each of the plurality of antennas is positioned so that each antenna establishes communications with a substantially distinct area of the earth.

Each of the antennas receives a plurality of communications from the earth stations. Each antenna also transmits a plurality of communications from the satellite to the earth stations. Each of the antennas is connected to a processor of the satellite for enabling the processor to receive and transmit messages from a number of earth stations.

The above and other objects, features, and advantages of the present invention will be better understood from the following detailed description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 depicts a satellite's projection of its antenna beams comprising the present invention.

FIG. 2 is a top view of the projection of the antenna beams onto the earth.

FIG. 3 is a side view of the antenna beam projections as shown in FIG. 2.

FIG. 4 depicts the intercept angle formed by the satellite's antenna beams.

FIG. 5 depicts a portion of the antenna horns of the present invention.

FIG. 6 is a two-dimensional representation of the antenna horn system of the present invention.

FIGS. 7*a*–7*d* depict the deployed horn structure and lens structure of the present invention.

FIG. 8 is a diagram of one particular horn of the antenna system of the present invention.

FIG. 9 is a block diagram of the monolithic microwave integrated circuit (MMIC) shown in FIG. 8.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The disclosures and teachings of U.S. patent application Ser. Nos. 263,849; 402,743; 415,842; 415,815; and 414,494 are hereby incorporated by reference.

FIG. 1 depicts satellite 100 projecting a multiple beam space antenna array. Satellite 100 includes a processor (not shown) for communication transmission and reception. Each hexagonal area, such as number 1, represents an individual cell which has been projected by an antenna beam. This projection shows cell 1 surrounded by three successively larger rings of similarly shaped cells. The cells actually projected by beams of satellite 100 for communications are elliptical in nature. The cells shown in FIG. 1 are the result of intersecting elliptical antenna beams. The six sides of each hexagon depict the chords which bisect the intersection of each of the elliptical beams.

In this configuration, 37 beams are projected by the antenna system of the satellite 100. Each of the 37 antenna is electrically and optically connected to the processor of the satellite. Since the satellite represents a point in space and the earth's surface is a sphere, it is necessary that each of the cells represent approximately the same area.

Each of the cells represents a plurality of frequencies about a center frequency. This aids in establishing communication between satellite 100 and a plurality of users in each particular cell on the earth. Since the satellite is in orbit about the earth, a communication link between a user in one cell and satellite 100 must be handed off to another adjacent cell as the satellite moves in orbit. The frequency assignment of the cells is such that there are four basic frequency groups used. A particular one of the four frequency groups is selected for center cell 1 area. Then, assignments are made circularly about cell 1 such that no two adjacent cells use the same one of the four frequency groups. This provides spatial diversity and for frequency re-use from group-to-group.

The 37 cells of FIG. 1 may be represented from a top view as shown in FIG. 2. The centermost ring A of the "bull's-eye" (concentric circles or rings) of FIG. 2 represents the center cell 1 of FIG. 1. The next, ring outside the center cell A is the ring B. Ring B includes six cells surrounding center cell 1. The ring adjacent to ring B is ring C. Ring C contains twelve cells surrounding ring B. The last ring surrounding ring C is ring D. Ring D contains eighteen cells surrounding ring C. As a result, in all the satellite projects 37 separate cells to provide an area of coverage for transmission uplinks and downlinks with respect to the satellite.

Each cell represents 1/37 of the total area of the entire cell pattern projected by a particular satellite. FIG. 3 depicts the total area from the satellite to the earth's surface. FIG. 3 is a side view and depicts the heights of the various rings as was shown in FIG. 2. That is, area 4 pertains to ring A, area 3 pertains to ring B, area 2 corresponds to ring C and area 1 corresponds to ring D. The total area of the satellite's projections may be calculated by the formula. area$=2\pi rh$, where r is the radius and h is the height of the spherical segment of the sphere and π=approximately 3.14159.

The area for each of the rings shown in FIGS. 2 and 3 as well as the total area may be calculated by the equations given below.

$$\text{Total area}=2\pi rh$$

$$\text{Area } 1=2\pi r(h-h1)$$

$$\text{Area } 2=2\pi r(h1-h2)$$

$$\text{Area } 3=2\pi r(h2-h3)$$

$$\text{Area } 4=2\pi rh3$$

FIG. 4 depicts the geometry of a particular satellite in orbit approximately 413 nautical miles above the earth's surface. It is assumed that the outside edge of ring D as shown in FIG. 2 when viewed from the satellite will intercept the earth at a 10 degree angle. This 10 degree angle 40 is termed the "mask angle". Satellite 45 is shown approximately 413 nautical miles above the earth's surface. From satellite 45 to the outer edge of ring D, as shown in FIG. 2, the distance 46 is approximately 1,243 nautical miles as shown in FIG. 4. The angle between the earth's surface and a line from the edge of outer ring D to satellite 45 is angle 40. This angle is the 20 degree mask angle.

Angle 41 is approximately 100 degrees. Angle 41 is made up of the 10 degree mask angle and a 90 degree tangent angle. The 90 degree tangent angle (angle 41 − angle 40) is comprised of a line segment 46 from the center of the earth to the earth's surface and the tangent to the earth's surface at that point (not shown). Angle 43 is the angle composed of line segments 47 from the satellite to the center of the earth and line segment 48 from the center of the earth to the point of the outer extent ring D. This angle is approximately 18.45 degrees. The distance from the center of the earth to the earth's surface is approximately 3,443 nautical miles, as shown in FIG. 4 line segment 47.

Angle 42 is the angle between line segments 46 and 47. Line segment 46 is a 1,243 nautical mile line segment between satellite 45 and the outer edge of ring D of the satellite's cell projections. Line segment 47 is a line directly from satellite 45 perpendicular to the earth's surface terminating at the center of the earth. For the present configuration shown in FIG. 4, angle 42 is approximately 61.55 degrees.

Referring again to FIGS. 1 and 2, the center of each of the six cells in ring B is equidistant from the center of the middle cell 1 (ring). The same is not true for the distance between the center of each cell and middle cell 1 for rings C and D.

Referring to FIG. 1, cell "a" is closer to the center of cell 1 than cell "b" is. Both cells a and b are located in the C cell ring. The C ring contains twelve cells. The "a" and "b" cells alternate around ring C. That is, ring C contains alternate "a" and "b" cells.

Similarly, ring D which is comprised of eighteen cells, includes "A" and "B" cells. Each of the A cells is equidistant to the center of cell 1. Each of the B cells is also equidistant with respect to the center of cell 1. However, the A cells are closer to the center of cell 1 than the B cells. With respect to ring D of the cells as shown in FIG. 1, the pattern of "A" and "B" cells is different than the "a" and "b" cells of ring C. Ring D has a pattern of one B cell and two A cells following. This pattern continues around ring D.

The angular differences from the satellite to the "a" and "b" cells or to the "A" and "B" cells must be accounted for in the positioning of each of the antennas of the satellite antenna system. For the purposes of further discussion, the a-b and A-B anomalies discussed above will not be taken into account. However, the positioning indications derived herein must be modified slightly to account for these anomalies in view of a specific altitude of the orbiting satellite.

For further discussions, rings C and D will be considered as having each cell equidistant to the center of cell 1. For a height of a satellite over the earth of 413 nautical miles, the resultant antenna angles for the 37 cells of FIG. 1 are shown summarized in Table 1. The center cell is cell ring A which is comprised of a single cell, cell 1. This cell size is approximately a 41.5 degree circle with respect to the satellite. This antenna would produce a gain of approximately 13.8 dB. In general, gain is calculated in terms of a maximum theoretical gain represented by an antenna of x radians by y radians. The formula for this gain is given as follows:

$$\text{Gain (dB)}=10\log(4\pi+xy)$$

The r^2 loss refers to the loss due to the range of the satellite from earth. This loss increases as the square of the range. Lastly, the mask angle represents the range of values for a line of sight from the ground to the satellite within a cell in that particular ring. There is only one cell in ring A.

The first actual ring of cells of Table 1 is ring B as shown in FIG. 2. The second and third rings of Table 1 correspond to rings C and D of FIG. 2 respectively.

TABLE 1

ANTENNA PARAMETERS - 413 NMI SATELLITE				
	CELL SIZE	GAIN	R^2 LOSS*	MASK ANGLE
CENTER CELL (A)	41.5° CIRCLE	13.8 dB	0.3 dB	67° TO 90°
FIRST RING (B)	22.3° × 60° ELLIPSE	14.9 dB	3.2 dB	40° TO 67°
SECOND RING (C)	10.5° × 30° ELLIPSE	21.2 dB	5.7 dB	26° TO 40°

TABLE 1-continued

ANTENNA PARAMETERS - 413 NMI SATELLITE				
	CELL SIZE	GAIN	R^2 LOSS*	MASK ANGLE
THIRD RING (D)	7.9° × 20° ELLIPSE	24.2 dB	91.5 dB	10° to 26°

*WORSE CASE RANGE LOSS COMPARED TO 413 NMI.

Table 2 depicts similar parameters for each of the cells shown in FIGS. 1 and 2 for a satellite at a height of 490 nautical miles over the earth. It is to be noted that the parameters for this increased height of the satellite are not substantially different from the first example given in Table 1.

TABLE 2

ANTENNA PARAMETERS - 490 NMI SATELLITE				
	CELL SIZE	GAIN	R^2 LOSS*	MASK ANGLE
CENTER CELL (A)	34.5° CIRCLE	15.4 dB	0.5 dB	70° TO 90°
FIRST RING (B)	20.5° × 60° ELLIPSE	15.3 dB	1.4 dB	46° TO 70°
SECOND RING (C)	11.1° × 30° ELLIPSE	20.9 dB	4.6 dB	31° TO 46°
THIRD RING (D)	9.75° × 20° ELLIPSE	23.4 dB	8.3 dB	13° to 31°

*WORSE CASE RANGE LOSS COMPARED TO 490 NMI.

Referring to Table 1, the antennas of the third ring or ring D require a 7.9 degree projection. As a result, an aperture of approximately 4 meters would be required. Small satellites or spacecraft may be typically a cylinder with a 2 meter height and a 1.5 meter approximate diameter. The present antenna array system may be transported via satellite by a cannister of approximately 1 meter diameter and 0.3 meters high.

Referring to FIG. 5, a cross section of the antenna array of the present invention is shown. FIG. 5 depicts horn antennas 50 through 56. These horn antennas represent antennas in each of the four rings A though E as mentioned in FIG. 2. Horn antenna 50 represents center cell 1 or ring A as shown in FIGS. 1 and 2 respectively. Horn antennas 51 and 52 represent two of the antennas within ring B as shown in FIG. 2. Horn antennas 53 and 54 represent two of the twelve antennas in ring C of the present antenna system. Lastly, horn antennas 55 and 56 represent two of the eighteen antennas in ring D of the antenna system.

First, it is to be noted that the antenna horns are disposed in a spherical configuration with antenna horn 50 which generates the center cell being at the center of the portion of the sphere. Second, it is to be noted that as we move from the center antenna 50 to antennas 51 and 52 of ring B that the length of the horn antenna is increased. Similarly, the horn antennas 53 and 54 of ring C are increased in size over 51 and 52 of ring B. Similarly, horn antennas 55 and 56 of ring B are longer than horn antennas 53 and 54 of ring C.

It can also be seen from the cross section of FIG. 5 that the antenna horns are mounted in a hemispherical position in order to achieve the cell projections shown in FIG. 1. The longest horns are those in ring D. The horns in ring D as exemplified by horns 55 and 56 would require an aperture of approximately 4 meters in length. The construction of the horns themselves may be of a metallized mylar. This antenna horn may be implemented as a spherically shaped mylar structure. This structure may be collapsed in a cannister prior to being placed into space. The antenna system may be deployed similar to the manner in which an inflatable rubber raft is inflated. That is, once the satellite is in proper position in space, the antenna may be deployed by inflation with a propellent in order for the antenna system to take its spherical shape of horn antennas.

FIG. 6 is a two-dimensional view of the horn antenna structure when deployed, looking up directly from beneath the satellite. Horn antennas 50 through 56 of FIG. 5 are shown depicted in FIG. 6. FIG. 6 shows that a view field from the satellite to the earth is the same in all directions. Horn antenna 50 appears as a circle. Antennas 51-56 appear as ellipses since they are angularly tilted.

Referring to FIG. 7A, the cannister mentioned above with the deflated horn antenna structure inside is shown. When the horn antenna system is inflated, its appearance would be similar to that shown in FIG. 7B. From this figure, as well as FIG. 5, it can be seen that the center horn antenna has the shortest length and the length of the horns increase as they move away from the center horn antenna of the structure. The diameter of the entire antenna system, that is, the outer diameter of ring D, may be approximately two feet.

Since antenna transmissions disperse over distance and these transmissions also produce sidelobes, a lens arrangement may be employed to suppress sidelobes and limit diffusion of the signals. FIG. 7C shows a bootlace lens in folded position which may be used to suppress sidelobes and limit diffusion. This bootlace lens is a planer lens. The bootlace lens is placed in front of the horn antenna structure, such that signals transmitted from the antennas or received by the antennas must pass through the planer lens. When the bootlace lens is deployed, its appearance would be as that of FIG. 7D. The bootlace lens may not be deployed in a similar fashion to the basic horn antenna structure. That is, the lens may not be inflated. The bootlace lens requires mechanical tuning. As a result, the bootlace lens may be constructed of a rigid material which would be deployed in planer sections similar to a solar cell array of a satellite.

FIG. 8 depicts one typical horn 80 of the multiple horn antenna array shown in FIG. 7B. Horn antenna 80 includes an inflatable truncated cone shape mylar structure 81. The interior surfaces of mylar cone 81 are metallized with conductive layer 82. This conductive layer or film may be implemented with such metals as gold or aluminum. Attached to the mylar cone is valve 83. Valve 83 provides for proper deployment of the cone structure 80 by inflation. Other valves (not shown) provide for inflating the supporting rubber raft structure mentioned above. Valve 83 is connected to a supply of gas (not shown) which is used to inflate the mylar structure upon deployment of the antenna system in space. Propellants such as nitrogen or foam may be used for inflation.

Microstrip to waveguide transition 87 is connected via an aperture 88 in the bottom portion of the cone to dielectric substrate 85. Dielectric substrate 85 provides for electrical isolation of the input and output signals as well as the mounting of MMIC circuitry 84. The microstrip to waveguide transition 87 provides for the reception and transmission of signals from radio, telephones or similar devices located on the earth. Incoming signals are transmitted from the waveguide structure 87 to the MMIC circuit 84. MMIC circuit 84 both receives and transmits signals and produces at its output an optical signal for transmission to or from the satellite's processor (not shown) via optical fiber 86. Coaxial cable may be used in place of the optical fiber 86.

Referring to FIG. 9, a block diagram of the MMIC (Microwave Monolithic Integrated Circuit) 84 of FIG. 8 is shown. Optical fiber 90 is connected to low level amplifier 91. Amplifier 91 is connected to power amplifier 92. Amplifier 92 is connected to circulator 93. Circulator 93 is connected to microstrip to waveguide transition 87. Microstrip waveguide 88 is connected to the horn antenna. Incoming signals are transmitted to microstrip 87. These signals are then transmitted to diplex 94 via circulator 93. Circulator 93 is also connected to diplexer 94. Diplexer 94 is connected to LNA (Low Noise Amplifier) 95. LNA 95 is connected to filter 96. Filter 96 is connected to amplitude modulation LED 97. Optic fiber 98 connects electrical to optical device 97 to the satellite's processor.

Optical signals are fransmitted via optical fiber 90 to FET amplifier 91. FET amplifier 91 converts the optical signal to an electrical signal and transmits this to MMIC power amplifier 92. Amplifier 92 produces an amplified signal which is transmitted through circulator 93 to the microstrip 87. Circulator 93 may comprise a waveguide with magnet. The circulator 93 transmits signals from an input node to an output node in the clockwise direction. In the counter clockwise direction signals from an input node are blocked. These signals are then transmitted through the horn to earth-based stations.

Incoming signals are transmitted through microstrip 87 through distributor 93 to diplexer 94. Diplexer 94 acts as a filter and removes transmitting or other undesirable frequencies. LNA 95 amplifies the signal. The incoming signals are then filtered by filter 96. The filtered signal is transmitted to electrical to amplitude modulation LED 97 which amplifies the signal and then amplitude modulates by superposition in a bias line a diode laser, light emitting diode or other similar device. The electrical signal is converted to an optical signal and transmitted via fiber 98 through the satellite's processor. The FET amplifier 91 may be implemented with a gallium arsenide FET. The light photons input to such a device cause modulation of the gate voltage of the FET. MMIC amplifier 92 may be implemented with a gallium arsenide MMIC amplifier.

Although the preferred embodiment of the invention has been illustrated, and that form described in detail, it will be readily apparent to those skilled in the art that various modifications may be made therein without departing from the spirit of the invention or from the scope of the appended claims.

What is claimed is:

1. A multiple beam space antenna system for facilitating communications between a satellite and a plurality of earth stations, said multiple beam space antenna system comprising:
   a plurality of antenna means disposed in a semispherical configuration about a surface of said satellite, each of said plurality of antenna means positioned so that each antenna means establishes said communications with a substantially distinct area of the earth, said plurality of antenna means including:
      a first plurality of antenna means circularly disposed;
      a second plurality of antenna means disposed circularly about said first plurality of antenna means; and
      a third plurality of antenna means disposed circularly about said second plurality of antenna means; and
   each of said antenna means for receiving a plurality of communications from said earth stations in a corresponding area and for transmitting a plurality of communications to said earth stations in said corresponding area; and
   each of said antenna means being connected to a processor of said satellite for enabling the processor to receive and transmit messages from a number of earth stations.

2. A multiple beam space antenna system as claimed in claim 1, wherein said first plurality of antenna means includes:
   antenna means centrally located with respect to said first, second and third pluralities of antenna means.

3. A multiple beam space antenna system as claimed in claim 2, wherein said antenna means and each of said first, second and third pluralities of antenna means project beams on a planet-like body such that said projected beams of said antenna means, said first plurality, said second plurality and said third plurality of antenna means are contiguous beams and form a large area for receiving and transmitting a plurality of signals between earth stations and said satellite.

4. A multiple beam space antenna system as claimed in claim 3, wherein said projected beams of said antenna means, said first plurality of antenna means, said second plurality of antenna means and said third plurality of antenna means form substantially concentric circular areas for facilitating communications between said satellite and said plurality of earth stations.

5. A multiple beam space antenna system as claimed in claim 4, wherein:
   said antenna means includes horn antenna means;
   said first plurality of antenna means includes a first plurality of horn antenna means;
   said second plurality of antenna means includes a second plurality of horn antenna means; and
   said third plurality of antenna means includes a third plurality of horn antenna means.

6. A multiple beam space antenna system as claimed in claim 5, wherein:
   said horn antenna means includes at least one horn antenna means;
   said first plurality of horn antenna means includes approximately six horn antenna means;
   said second plurality of horn antenna means includes approximately twelve horn antenna means; and
   said third plurality of horn antenna means includes approximately eighteen horn antenna means.

7. A multiple beam space antenna system as claimed in claim 5, wherein each of said beams projected by said horn antenna means, said first plurality of horn antenna means, said second plurality of horn antenna means and said third plurality of horn antenna means are substantially hexagonal in shape.

8. A multiple beam space antenna system as claimed in claim 5, wherein:

said horn antenna means includes cone means of a first length;

said first plurality of horn antenna means each including cone means of a second length being greater than said first length;

said second plurality of horn antenna means each including cones means of a third length being greater than said second length; and

said third plurality of horn antenna means each including cone means of a fourth length being greater than said third length.

9. A multiple beam space antenna system as claimed in claim 8, wherein there is further included inflatable means for supporting each of said horn antenna means, said inflatable means for support and each of said cone means being inflated to produce said spherical configuration of said pluralities of said horn antenna means.

10. A multiple beam space antenna system as claimed in claim 5, wherein there is further included cannister means for containing each of said pluralities of said horn antenna means and said inflatable means for support on board said satellite, so that said inflatable means for support may be removed from said cannister means during orbiting of said satellite.

11. A multiple beam space antenna system as claimed in claim 5, wherein there is further included lens means positioned between said plurality of horn antenna means and said projections of said beams on said planet-like body, said lens means operating to focus said beams of said plurality of horn antennas.

12. A multiple beam space antenna system as claimed in claim 11, wherein said lens means includes bootlace lens means.

13. A multiple beam space antenna system as claimed in claim 12, wherein said bootlace lens means includes folding bootlace lens means.

14. A multiple beam space antenna system as claimed in claim 5, wherein each of said horn antenna means includes:

truncated cone means including a truncated portion for projecting said beams upon said planet-like bodies;

coating means applied to said inner surface of said truncated cone means;

waveguide means positioned centrally to said truncated portion of said truncated cone means, said waveguide means for translating electronic signals to RF signals and for translating RF signals to electronic signals;

circuit means connected to said waveguide means, said circuit means operating to interface signals between said processor of said satellite and said waveguide means; and

connection means connected between said circuit means and said processor of said satellite, said connection means operating to transmit signals between said circuit means and said processor.

15. A multiple beam space antenna system as claimed in claim 14, wherein said truncated cone means includes mylar truncated cone means.

16. A multiple beam space antenna system as claimed in claim 15, wherein there is further included inflation means connected to said mylar truncated cone means, said inflation means operating to permit inflation of said mylar truncated cone means to a particular predetermined shape.

17. A multiple beam space antenna system as claimed in claim 14, wherein said coating means includes metallized coating means such as aluminum.

18. A multiple beam space antenna system as claimed in claim 17, wherein said metallized coating means comprises gold.

19. A multiple beam space antenna system as claimed in claim 14, wherein said connection means includes optic fiber means.

20. A multiple beam space antenna system as claimed in claim 14, wherein said connection means includes coaxial cable means.

21. A multiple beam space antenna system as claimed in claim 14, wherein there is further included dielectric substrate means connected to said circuit means and to said waveguide means, said dielectric substrate means for supporting said circuit means and said waveguide means.

22. A multiple beam space antenna system as claimed in claim 14, wherein said circuit means includes:

low level amplifier means connected to said processor, said low level amplifier means for converting optic signals to electronic signals;

power amplifier means connected to said low level amplifier means;

circulator means connected to said power amplifier, said circulator means having three input and output ports and operating to transmit signals from an input port to an output port in a clockwise direction only; and

said waveguide means being connected to said circulator means.

23. A multiple beam space antenna system as claimed in claim 22, wherein said circuit means further includes:

diplexer means connected to said circulator means, said diplexer means operating to pass only received signals;

low noise amplifier means connected to said diplex means;

filter means connected to said low noise amplifier means; and

amplitude modulation means connected between said filter means and said processor of said satellite.

24. A multiple beam space antenna system as claimed in claim 22, wherein said connection of said processor to said low level amplifier means and said connection of said amplitude modulation means to said processor each include optic fiber.

25. A multiple beam space antenna system for facilitating communications between a satellite and a plurality of earth stations, said multiple beam space antenna system comprising:

a plurality of antenna means disposed in a semispherical configuration about a surface of said satellite, each of said plurality of antenna means positioned so that each antenna means establishes said communication with a substantially distinct area of the earth;

said plurality of antenna means including a plurality of horn antenna means having waveguide means for transmitting and receiving RF signals and circuit means for interfacing between said waveguide means and a processor of said satellite;

inflatable support means for positioning each of said plurality of horn means in said spherical configuration;

each of said antenna means for receiving a plurality of communications from said earth stations in a corresponding area and for transmitting a plurality of communications to said earth stations in said corresponding area; and

each of said antenna means being connected to said processor of said satellite for enabling the processor to receive and transmit messages.

* * * * *

D

Attachment D

CALIBRATED METHOD AND DEVICE FOR NARROW BAND DOPPLER COMPENSATION

U.S. PATENT NO. 5,095,538

(MARCH 10, 1992)

US005095538A

United States Patent [19]

Durboraw, III

[11] Patent Number: 5,095,538

[45] Date of Patent: Mar. 10, 1992

[54] CALIBRATED METHOD AND DEVICE FOR NARROW BAND DOPPLER COMPENSATION

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[73] Assignee: Motorola, Inc., Schaumburg, Ill.

[21] Appl. No.: 414,494

[22] Filed: Sep. 29, 1989

[51] Int. Cl.[5] H04B 7/01

[52] U.S. Cl. 455/71; 455/316; 370/104.1

[58] Field of Search .... 455/52, 65, 71, 99, 455/63, 316, 317, 343; 331/1 A; 342/99, 418; 375/1, 98; 370/104.1

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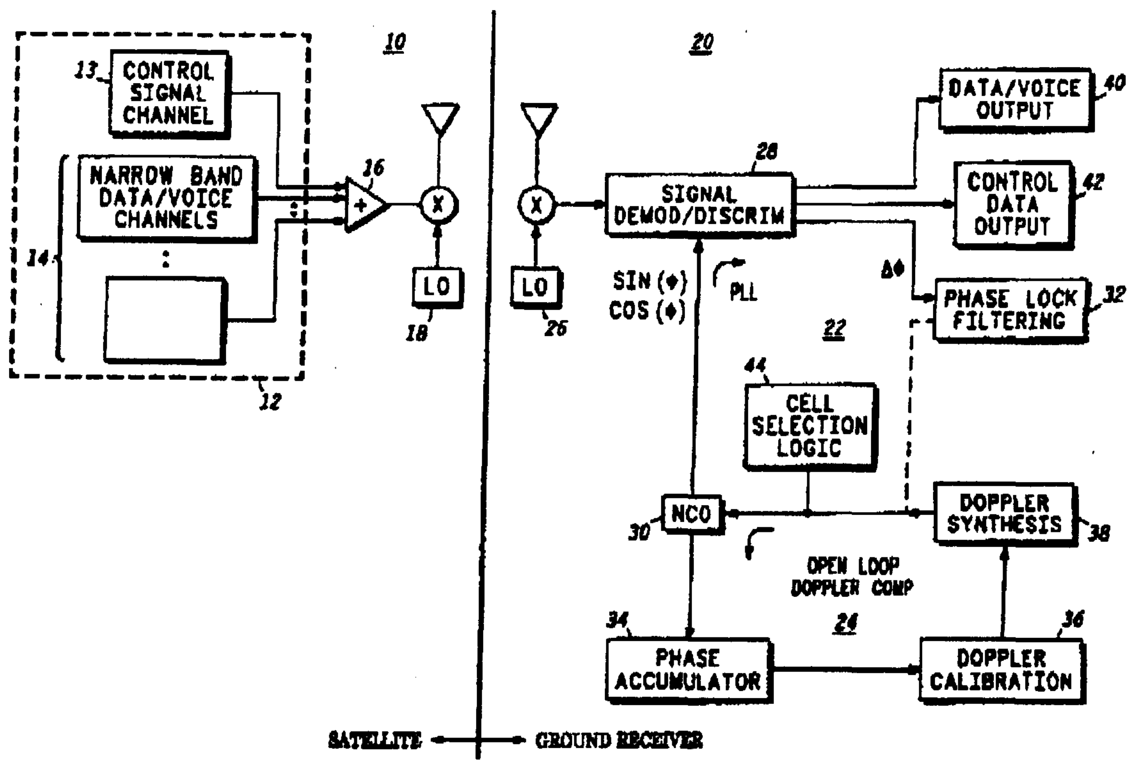
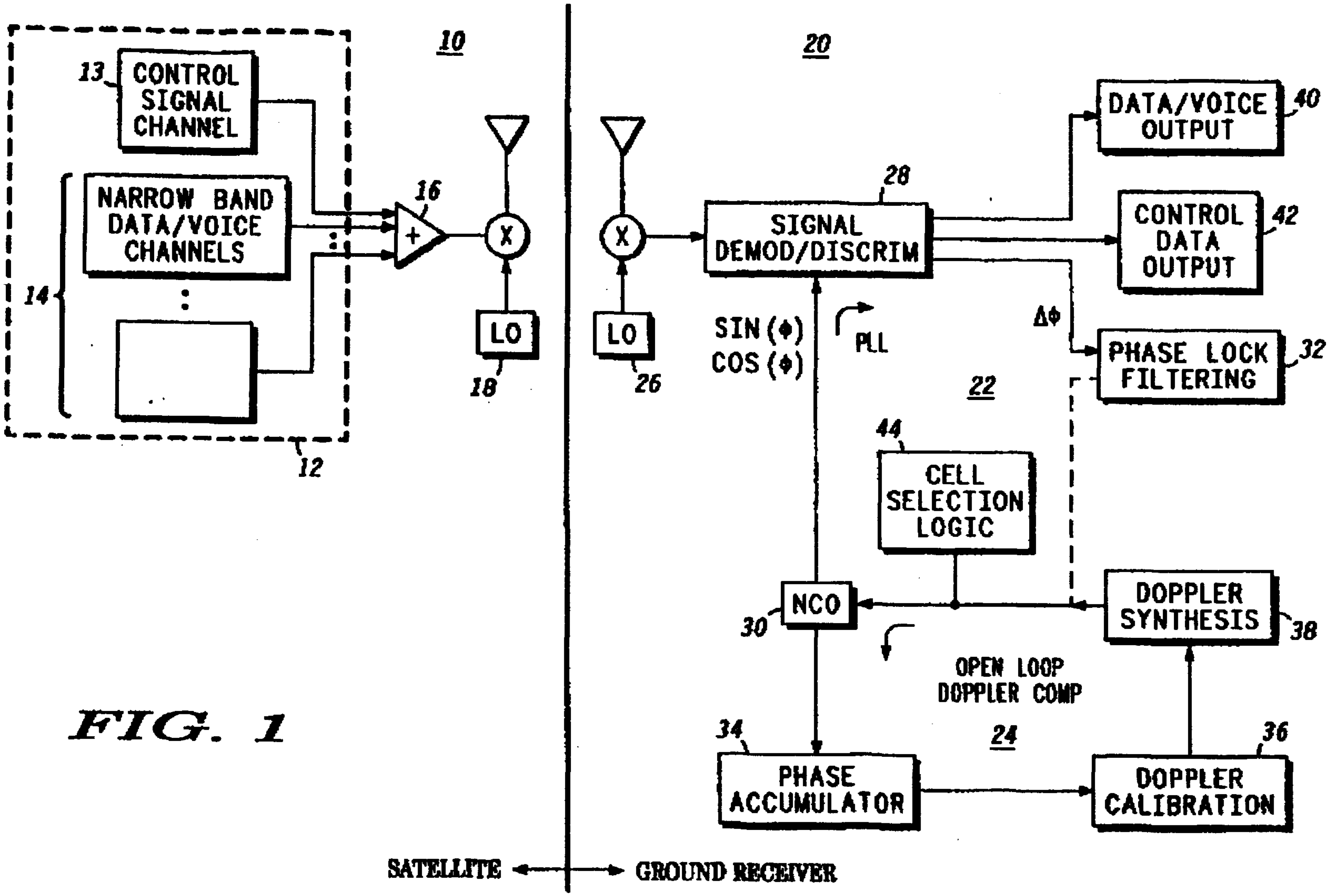
Primary Examiner—Curtis Kuntz
Assistant Examiner—Edward Urban
Attorney, Agent, or Firm—Frank J. Bogacz

[57] ABSTRACT

A Doppler compensating device which conserves power and can be used with hand-held communication devices comprises a phase lock loop for tracking a Doppler phase offset and a Doppler offset calibration loop which generates a Doppler offset curve. The Doppler offset calibration loop extracts Doppler offset points from the phase lock loop, and from these points calibrates a set of three parameters defining the Doppler offset curve using an estimation algorithm such as the least squares algorithm. After the curve is defined, the compensation device extracts points from the Doppler offset curve and deactivates the phase lock loop. This process preserves power within the hand-held communication devices.

10 Claims, 3 Drawing Sheets




10
20
CONTROL SIGNAL CHANNEL
13
NARROW BAND DATA/VOICE CHANNELS
14
12
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LO
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LO
26
SIGNAL DEMOD/DISCRIM
28
DATA/VOICE OUTPUT
40
CONTROL DATA OUTPUT
42
PHASE LOCK FILTERING
32
Δϕ
SIN (ϕ)
COS (ϕ)
PLL
22
CELL SELECTION LOGIC
44
NCO
30
DOPPLER SYNTHESIS
38
OPEN LOOP DOPPLER COMP
24
PHASE ACCUMULATOR
34
DOPPLER CALIBRATION
36
SATELLITE
GROUND RECEIVER

FIG. 1

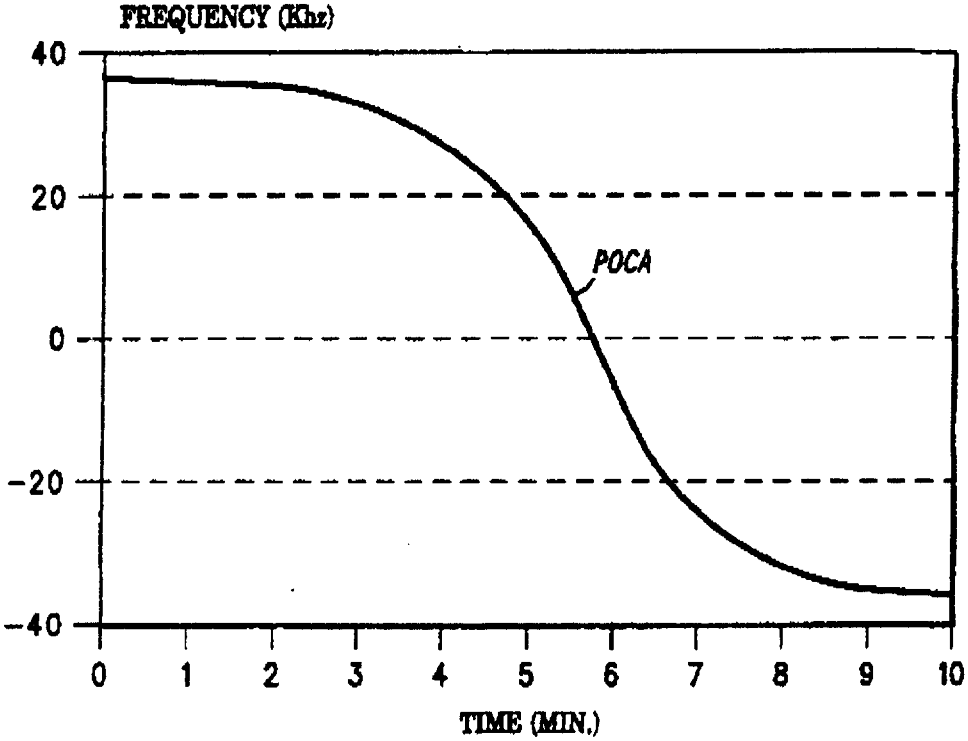

FIG. 2

TYPICAL DOPPLER FREQUENCY OFFSET CHARACTERISTICS (L=400 MILES)

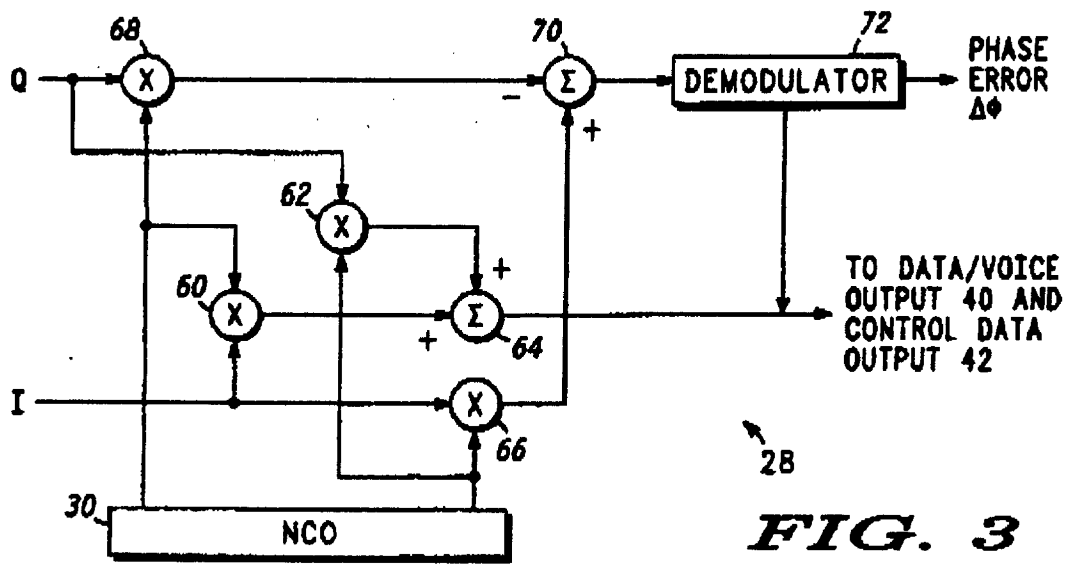

FIG. 3

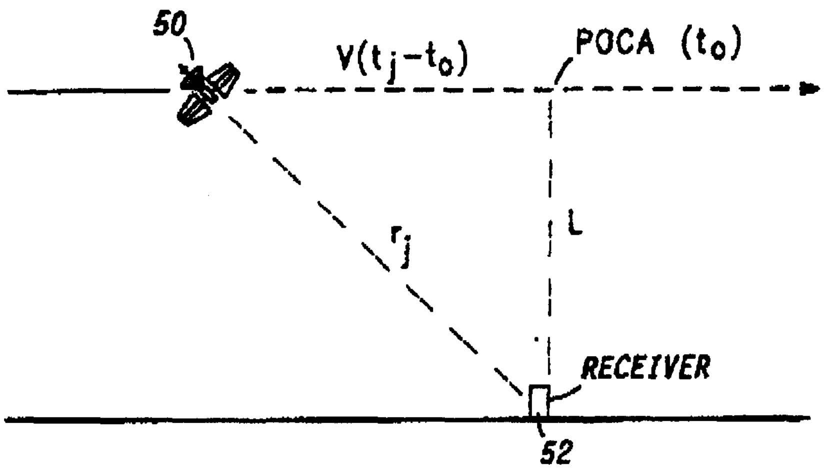

FIG. 4
CONSTANT VELOCITY MODEL
FOR DOPPLER COMPENSATION

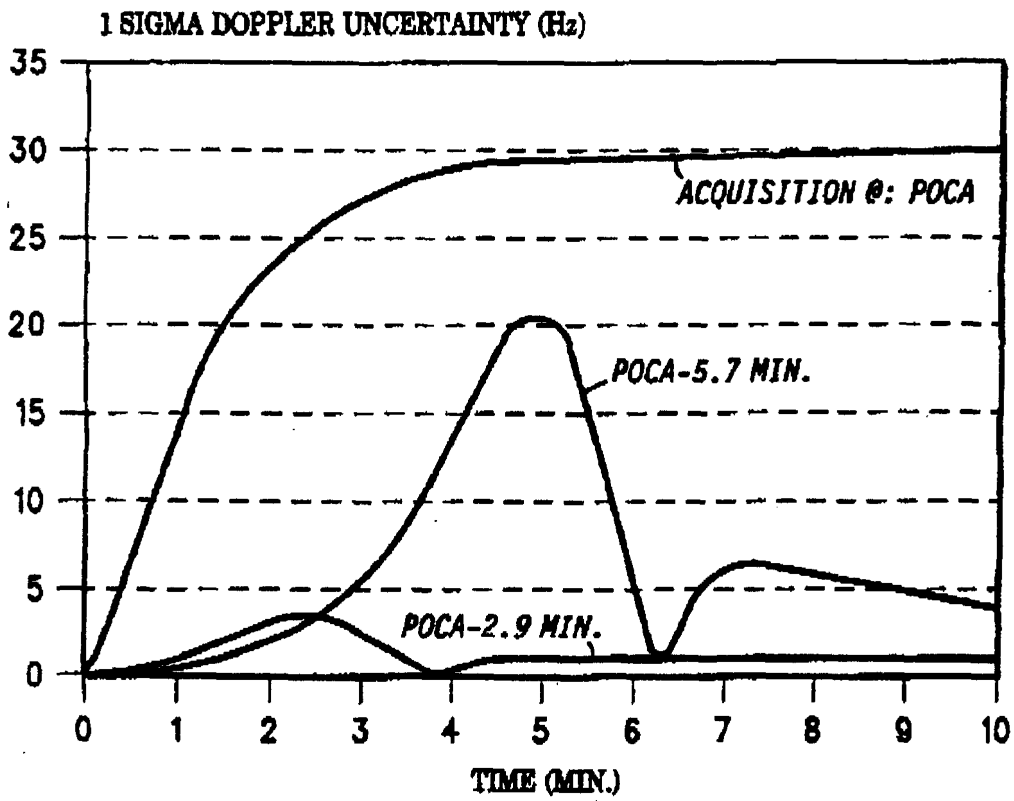

FIG. 5
DOPPLER PREDICTION UNCERTAINTY
L=400 MILES; 7 SAMPLES • 1.0 SEC SPACING

CALIBRATED METHOD AND DEVICE FOR NARROW BAND DOPPLER COMPENSATION

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is related to co-pending U.S. patent applications Ser. Nos. 263,849, Satellite Cellular Telephone and Data Communication System, 402,743, Power Management System For A Worldwide Multiple Satellite Communications System, 415,814, Multiple Beam Deployable Space Antenna System, 415,842, Telemetry, Tracking and Control For Satellite Cellular Communication Systems, and 415,815, A Method To Optimize Cell-To-Cell Handoffs In A Satellite Cellular System.

BACKGROUND OF THE INVENTION

This invention relates, in general, to Doppler compensation, and more specifically, to calibration of Doppler within a narrow bandwidth.

Satellites are becoming important links for communication between stations at different locations throughout the world, particularly for mobile communication units. Such mobile communication units, particularly hand held communication units, inherently operate on low power. To operate with low power, the hand-held communication units must be designed for narrow band signals for efficiency. Typical applications for narrow band designs include hand-held units which must communicate with low orbiting satellites (e.g. approximately 400 n. mi.).

The Doppler effect on signals transmitted between a mobile communication unit and a satellite becomes distorted, particularly for low-earth-orbiting satellites. The distortion caused by Doppler must be removed for the information to be extracted when the communication channel is narrow (e.g. 3 Khz). For instance, a signal transmitted to earth from a low orbiting satellite would have a frequency variation due to Doppler of ±35 Khz at a center frequency of 1.5 Ghz over a period of 10 to 15 minutes. Voice channels of 3 Khz would require guard band of approximately 12 channel widths between voice/data channels to avoid interference between channels. When the channel width is even smaller, as with pagers having a band width of 300 Hz, the guard band increases to over 200 channel widths.

The problem of guard band width may be overcome by transmitting a pilot signal or control signal in a single dedicated channel. The control signal must be sufficiently separated from the voice/data signals that the voice/data signals do not interfere with the control signal. Terrestrial receivers search for the control signal, and use the control signal to direct data traffic for the other channels. By separating the control signal from all other signals, the Doppler effect on the control signal can be determined and applied to the voice/data channels. This avoids tracking Doppler on the voice/-data channels.

Continuous tracking of the control signal to obtain Doppler requires a continuous supply of power. For low-power hand-held units, such as pagers and hand-held cellular telephones, continuous tracking of Doppler is inefficient and undesirable.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a Doppler compensating device which does not require continuous tracking of Doppler, and permits operating with minimal power.

A Doppler compensating device whhich conserves power and can be used with hand-held communication devices comprises a phase lock loop for tracking a Doppler phase offset and a Doppler offset calibration loop which generates a Doppler offset curve. The Doppler offset calibration loop extracts Doppler offset points from the phase lock loop, and from these points calibrates a set of three parameters defining the Doppler offset curve using an estimation algorithm such as the least squares algorithm. After the curve is defined, the compensating device extracts points from the Doppler offset curve and deactivates the phase lock loop. This process preserves power within the hand-held communication devices.

The above and other objects, features, and advantages of the present invention will be better understood from the following detailed description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a block diagram of Doppler compensating device according to the present invention.

FIG. 2 is a Doppler frequency offset curve for given parameters.

FIG. 3 is a diagram of a signal demodulator/discriminator for the Doppler compensating device of FIG. 1.

FIG. 4 is a diagram of a simplied model of a low-orbit satellite system showing a satellite communicating with a terrestrial receiver.

FIG. 5 is a graph representing calibration error for three acquisition times according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The following U.S. patent applications are related to the present invention, and the teachings of the applications are hereby incorporated by reference:

U.S. patent application Ser. Nos. 263,849, Satellite Cellular Telephone and Data Communication System,

402,743, Power Management System For A Worldwide Multiple Satellite Communications System,

415,814, Multiple Beam Deployable Space Antenna System,

415,842, Telemetry, Tracking and Control For Satellite Cellular Communication Systems, and

415,815, A Method To Optimize Cell-To-Cell Handoffs In A Satellite Cellular System.

The present invention is particularly applicable to low-power, hand-held communication units such as paging devices and hand-held cellular telephones. However, the invention may also be applied to high-power communication units experiencing Doppler effects.

To reduce power consumption within the hand-held unit, the present invention incorporates two Doppler defining loops within a receiver 20 as shown in FIG. 1. The first loop, a phase locked loop (PLL) 22, initially tracks the Doppler in signals received from a transmitter 10. The second loop, labelled open loop Doppler compensation (OLDC) 24, samples phase errors from PLL 22 to determine a Doppler curve, and uses the curve to define the Doppler for subsequently received signals. Open loop Doppler compensation 24 requires minimal power and allows PLL 22 to turn off.

The specific elements of transmitter 10 comprise a plurality of channels 12 where a first channel 13 is dedicated specifically to a control signal, and voice/data channels, designated 14, are used for voice/data signals. All channels of plurality of channels 12 are summed in summing amplifier 16, and the output of summing amplifier 16 is mixed with a carrier from local oscillator (LO) 18. This modulated signal is transmitted to receiver 20. It should be recognized that the control signal of first channel 13 determines the data flow of voice/data channels 14 within receiver 20. The control signal also operates as a pilot tone to allow tracking of the Doppler by receiver 20.

When the modulated signal from transmitter 10 is received by receiver 20 it is demodulated by LO 26, and the I and Q baseband signals are relayed to signal demodulator/discriminator (dem/disc) 28. Dem/disc 28 multiplies the I and Q baseband signals with sine and cosine signals received from a numerically controlled oscillator (NCO) 30. The output of signal dem/disc 28 is the phase error $\Delta\phi$ which is filtered through phase lock filter 32. Phase lock filter 32 outputs a measure of the loop phase error, $\Delta\phi$, to NCO 30 to control the output of NCO 30. Demo/disc 28, phase lock filter 32, and NCO 30 constitute PLL 22.

Since the satellite of transmitter 10 is constantly moving, the Doppler on the signal received by receiver 20 is constantly changing. While PLL 22 is active, PLL 22 will lock onto the phase of the input signal and track the Doppler as it changes. The correction sine and cosine signals generated by NCO 30 are used within demo/disc 28 to correct the signals from voice/data channels 14 for Doppler effects.

As PLL 22 tracks the changing Doppler, a phase accumulator 34 within OLDC 24 samples the amplitudes of the $\Delta\phi$ generated by phase lock filter 32. Each sample is transmitted to a Doppler calibration 36. After several samples have been taken and transmitted to Doppler calibration 36, preferably about 7 samples taken at one second intervals, Doppler calibration 36 uses the samples in an algorithm to generate a predicted Doppler curve for the particular satellite being tracked. FIG. 2 represents a Doppler curve generated by Doppler calibration 36 for a satellite having an orbit 400 miles above the earth. Typically a satellite used to, is tracked for approximately 10 minutes. At the beginning and ending reaches of the tracking period, the Doppler effect on the signals is greatest. As the satellite passes through a point of closest approach (POCA), the Doppler effect is at its lowest.

Referring again to FIG. 1, points along the curve generated by Doppler calibration 36 are extracted by Doppler synthesis 38 and Doppler synthesis 38 generates a voltage representing the magnitude of each extracted point. Since the time of initial tracking is known, and the Doppler curve is defined according to the initial point of tracking, Doppler synthesis 30 can correspond points extracted from the curve with signals received from transmitter 10. The voltage generated by Doppler synthesis is relayed to NCO 30 to control the values of the sine and cosine outputs of NCO 30.

As Doppler synthesis 38 begins to extract points from the Doppler curve, PLL 22 is no longer needed to track the curve. Therefore, the power to PLL 22 is turned off. This reduces the power usage within receiver 20.

FIG. 3 is a detailed schematic of demo/disc 28. As seen in FIG. 3, NCO 30 generates a Doppler offset frequency, represented by the cosine and sine outputs,

which are relayed to demo/disc 28. In demo/disc 28, a first portion of the cosine and sine signals are multiplied in mixers 60 and 62 respectively, with a first portion of the I and Q components of the voice/data signals and the control signal. Since the cosine and sine signals generally represent the Doppler phase error within the signals, the result is Doppler compensated data signals. The corrected I and Q components are recombined in summer 64 and the signals corresponding to data/voice channels 14 are output at data/voice output 40 of FIG. 1. Similarly, the signals corresponding to control signal channel 13 are output to control data output 42 of FIG. 1.

A second portion of the sine value received from NCO 30 is multiplied in multiplier 66 with a second portion of the I component of the control signal. A second portion of the cosine value is multiplied in multiplier 68 with a second portion of the Q component of the control signal within demo/disc 28. The I and Q components are then recombined in summer 70. The combined signal from summer 70 is multiplied in demodulator 72 with the corrected voice/data signals from summer 64 to form the phase error $\Delta\phi$ which is used within PLL 22.

The predicted Doppler/time-dependent frequency offset to generate the curve of FIG. 2 is determined by modeling the satellite motion with 2 parameters, L and t_o where L is the range to the satellite at POCA and t_o is time at POCA. Referring now to FIG. 4, satellite 50 has a known velocity, V, at a distance L from receiver 52 at POCA, t_o. The instantaneous range of satellite 50 at any point along its flight is r_j. This instantaneous range includes situations where satellite 50 does not travel directly over receiver 52. The range of satellite 50 from receiver 52 at some time t_j is defined by:

$$r_j=[L^2+V^2(t_j+t_o)^2]^{\frac{1}{2}} \qquad (1)$$

The observed carrier phase at t_j is expressed in terms of the combined effect of the range and the accumulated phase due to frequency offset δf_o:

$$\bar{\rho}_j=r_j+\lambda\delta f_o(t_j-t_o)+w_j,\ (j=1,2,3,\ldots,n) \qquad (2)$$

where:

λ = wavelength of transmission

δf_o = Local oscillator frequency offset (which is modeled as a constant) of receiver 52 relative to satellite 50

w_j = noise in measurement of the carrier phase.

Given a set of observations ρ_j, (j=1, 2, 3, . . . n), as accumulated by phase accumulator 34 of FIG. 1, the three characteristic parameters of the Doppler curve are L, δf_o, and t_o, and can be estimated. V is not estimated since V is well established as an orbital parameter.

The most direct method for estimating L, δf_o, and t_o is the iterative least squares estimation method. An initial estimate is used to compute an estimated set of observations by:

$$\begin{aligned}\hat{\rho}_j &= \hat{r}_j+\lambda\delta\hat{f}_o(t_j-\hat{t}_o) \\ &= (\hat{L}^2+V^2(t_j-\hat{t}_o)^2)^{\frac{1}{2}}+\lambda\delta\hat{f}_o(t_j-\hat{t}_o)\end{aligned} \qquad (3)$$

$$j=1,2,3,\ldots n$$

where the hat ($\hat{}$) denotes an estimated quantity. The least squares estimate is formed by iteratively computing a three dimensional correction vector, $\delta\hat{x}$, whose elements are $\delta\hat{f}_0$, $\delta\hat{L}$, and $\delta\hat{t}_0$, from the equation:

$$\delta\hat{x} = \left[\sum_{j=1}^{n} h_j h_j^T\right]^{-1} \left[\sum_{j=1}^{n} h_j(\tilde{\rho}_j - \hat{\rho}_j)\right] \tag{4}$$

where h_j and its transpose h_j^T are sensitivity vectors. The tilde ($\sim$) denotes a measured quantity. The product of the vectors h_j and h_j^T form a 3-by-3 matrix (commonly referred to as a dyadic) whose elements are:

$$[h_j h_j^T] = \begin{pmatrix} h_1h_1 & h_1h_2 & h_1h_3 \\ h_2h_1 & h_2h_2 & h_2h_3 \\ h_3h_1 & h_3h_2 & h_3h_3 \end{pmatrix}$$

The sensitivity vectors h_j are defined as follows:

$$h_j = \begin{pmatrix} (t_j - \hat{t}_0)\lambda \\ L/r_j \\ -\delta\hat{f}_0\lambda - (t_0 - \hat{t}_0)\hat{V}^2/\hat{r}_j \end{pmatrix} \tag{5}$$

Having solved for δx, the parameters of the Doppler curve are updated with the vector equation:

$$x_{new} = x_{old} + \delta\hat{x} \tag{6}$$

where x_{new} and x_{old} are 3 dimensional vectors whose elements are the new and old iterative estimates of the quantities L, δf_o, and t_o, respectively. The iteration process ends when $\delta\hat{x} = 0$.

The accuracy of the Doppler curve estimates are dependent upon the first observations of the satellite trajectory relative to POCA and can be assessed using through covariance analysis. One familiar with the least squares estimation will recognize that the error covariance of the estimate of Equation 4 is expressed as a covariance matrix P where

$$P = e\{[\delta\hat{x} - \delta x]\,[\delta\hat{x} - \delta x]^T\} = \left[\sum_{j=1}^{n} h_j h_j^T\right]^{-1} \sigma_\phi^2 \tag{7}$$

where e{} is the expectation operator and θ_ϕ is the one sigma random error expected in the measurement of the signal phase for the receiver.

The error covariance matrix, P, is a 3-by-3 matrix charaterizing the uncertainty in estimating the three parameters of the Doppler curve. Since the parameters are used to define the predicted Doppler offset during the entire observation period, the uncertainity of the Doppler curve may be evaluated at representative points along the observation period.

The Doppler predicted offset frequency for the k^{th} time point (ie. not limited to the first n points used in Equation 4) is computed from the time derivative of the observed signal phase (Equation 2) as

$$\delta\hat{f}_k = \dot{\hat{\rho}}_k/\lambda = [\lambda\delta\hat{f}_o + \hat{V}^2(t_k - \hat{t}_o)/\hat{r}_k]/\lambda \tag{8}$$

The subscript k used here is distinct from the j used in the calibration of the Doppler parameters.

The error in the Doppler offset is defined as the perturbation of Equation 8 and is

$$\delta(\delta\hat{f}_k) = \delta\dot{\hat{\rho}}_k/\lambda = \beta_k^T(\delta\hat{x} - \delta x) \tag{9}$$

where β is the three dimensional perturbation sensitivity vector:

$$\beta_k = \begin{pmatrix} 1 \\ -V^2L(t_k - t_o)/(\lambda r_k^3) \\ -(V^2/r_k)[1 - V^2(t_k - t_o)^2/r_k^2]/\lambda \end{pmatrix}$$

By combining Equations 9 and 7, the variance of the error in the Doppler offset is expressed as

$$\sigma_{\delta f_k} = [\beta_k^T P \beta_k]^{\frac{1}{2}} \tag{10}$$

This function may be evaluated for a range of configurations to demonstrate the feasibility of calibrating the Doppler characteristics based on a very short sample of the signal received from the control signal channel 13 of FIG. 1. FIG. 5 graphically represents Doppler uncertainty vs. time for samples taken 5.7 minutes before POCA, 2.9 minutes before POCA, and at POCA. The graph assumes calibration points taken over a span of 6 seconds, with acquisition and Doppler calibration occuring at three different points during the pass of a satellite orbiting at 400 miles. In general, the longer the data span, the more accurate the calibration of the Doppler curve. As indicated in FIG. 5, with 7 samples spanning a period of 6 seconds, the entire Doppler curve can be predicted to within 10 percent of a pager bandwidth of 300 Hz. More favorable results occur when acquisition occurs at 2.9 minutes prior to POCA. The prediction accuracy becomes slightly degraded at POCA.

Referring again to FIG. 1, a cell selection logic 44 is coupled to the input of NCO 30. The amplitude of the voltage received at this point represents the phase error $\Delta\phi$. This value, due to its changing nature resulting from the movement of the satellite, can be used to determine when a signal transmitted or received within a particular cell must be transferred to an adjoining cell. The cell-to-cell handoff is discussed in the previously referred to application "A Method To Optimize Cell-To-Cell Handoffs In A Satellite Cellular System."

Thus there has been provided, in accordance with the present invention, a calibrated method and device for narrow band Doppler compensation that fully satisfies the objects, aims, and advantages set forth above. While the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications, and variations will be apparent to those skilled in the art in light of the foregoing description. Accordingly, it is intended to embrace all such alternatives, modifications, and variations as fall within the spirit and broad scope of the appended claims.

We claim:

1. A low-power Doppler compensating device comprising:

first means for tracking a dynamic Doppler phase shift from an input signal to generate a first Doppler correction signal;

said input signal having a Doppler phase shift due to predictable relative motion between a transmitter and a receiver;

second means for generating a Doppler offset curve for a dynamic Doppler phase shift, said second means generating a second Doppler correction signal;

said second means coupled to said first means to receive a set of Doppler phase shift samples to calibrate said Doppler offset curve;

third means for removing said Doppler phase shift from said input signal, said third means coupled to said first means and to said second means; and

said third means receiving said first Doppler correction signal for a given time, after which said third means receives said second Doppler correction signal.

2. A low-power Doppler compensating device according to claim 1 wherein said first means for tracking comprises a phase lock loop.

3. A low-power Doppler compensating device according to claim 1 wherein said second means for generating comprises an open loop time dependent compensator.

4. A low-power Doppler compensating device according to claim 3 wherein said second means for generating comprises:

accumulator means for extracting said set of Doppler phase shift samples from said first means, said accumulator means accumulating said extracted set of Doppler phase shift samples;

calibration means for generating calibration parameters representing said Doppler offset curve from said set of Doppler phase shift samples, said calibration means coupled to said accumulator means to receive said accumulated extracted set of Doppler phase shift samples;

synthesis means for extracting said calibration parameters representing said Doppler offset curve, said synthesis means coupled to said calibration means to extract said calibration parameters;

said synthesis means generating frequency estimates from said calibration parameters;

numerically controlled oscillator (NCO) coupled to said synthesis means to receive said frequency estimates, said NCO generating said second Doppler correction signal from said frequency estimates; and

said NCO coupled to said third means to relay said second Doppler correction signal to said third means and said NCO coupled separately to said accumulator means.

5. A low-power Doppler compensating device according to claim 1 wherein said second means for generating comprises:

accumulator means for extracting said set of Doppler phase shift samples from said first means, said accumulator means accumulating said extracted set of Doppler phase shift samples;

calibration means for generating calibration parameters representing said Doppler offset curve from said set of Doppler phase shift samples, said calibration means coupled to said accumulator means to receive said accumulated extracted set of Doppler phase shift samples;

synthesis means for extracting said calibration parameters representing said Doppler offset curve, said synthesis means coupled to said calibration means to extract said calibration parameters;

said synthesis means generating frequency estimates from said calibration parameters;

numerically controlled oscillator (NCO) coupled to said synthesis means to receive said frequency estimates, said NCO generating said second Doppler correction signal from said frequency estimates; and

said NCO coupled to said third means to relay said second Doppler correction signal to said third means and said NCO coupled separately to said accumulator means.

6. A low-power Doppler compensating device according to claim 1 wherein said third means comprises a signal demodulator/discriminator.

7. A method for adjusting an input signal for Doppler offset comprising the steps of:

tracking the Doppler offset in a phase lock loop (PLL);

generating a Doppler correction signal within said PLL;

modulating said Doppler correction signal with said input signal;

extracting and storing Doppler phase shift samples from said PLL;

generating calibration parameters defining a Doppler offset curve;

synthesizing frequency estimates from said calibration parameters;

generating a frequency command from said frequency estimates;

generating said Doppler correction signal from said frequency command;

deactivating said PLL; and

modulating said input signal with said Doppler correction signal.

8. A method of adjusting an input signal for Doppler offset according to claim 7 wherein said step of generating calibration parameters defining a Doppler offset curve comprises the step of calculating said calibration parameters using a least squares algorithm.

9. A method for adjusting an input signal for Doppler offset according to claim 8 wherein said step of calculating said calibration parameters using a least squares algorithm comprises:

calculating a Doppler estimate using the algorithm

$$\begin{aligned}\hat{\rho}_j &= \hat{r}_j + \lambda\hat{\delta}/\hat{f}_o(t_j - \hat{t}_o)\\ &= (\hat{L}^2 + \hat{V}^2(t_j - \hat{t}_o)^2)^{1/2} + \lambda\hat{\delta}/\hat{f}_o(t_j - \hat{t}_o)\end{aligned}$$

$j = 1, 2, 3, \ldots n$

calculating sensitivity vectors using the algorithm

$$h_j = \begin{pmatrix} (t_j - \hat{t}_o)\lambda \\ \hat{L}/\hat{r}_j \\ -\hat{\delta}/\hat{f}_o\lambda - (t_o - \hat{t}_o)\hat{V}^2/\hat{r}_j \end{pmatrix};$$

calculating a correction vector using the algorithm

$$\delta\hat{x} = \left[\sum_{j=1}^{n} h_j h_j^T\right]^{-1}\left[\sum_{j=1}^{n} h_j(\tilde{\rho}_j - \hat{\rho}_j)\right];$$

calcualting a new value of x using the algorithm $x_{new} = x_{old} + \delta\hat{x}$; and

iterating from the step of calculating a Doppler estimate until $\delta\hat{x} = 0$.

10. A method for adjusting an input signal for Doppler offset according to claim 7 wherein said step of synthesizing frequency estimates comprise the step of compensating a receiver reference frequency from a predicted offset frequency using the algorithm

$$\delta\hat{f}_k = \hat{\rho}_k/\lambda = [\lambda\delta\hat{f}_o + V^2(t_k - \hat{t}_o)/\hat{r}_k]/\lambda.$$

* * * * *

E

Attachment E

COVER LETTER

REGARDING CONFIDENTIAL TREATMENT

OF

PROPRIETARY AND CONFIDENTIAL MATERIALS

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April 10, 1992

DELIVERY BY HAND

Ms. Donna R. Searcy
Secretary
Federal Communications Commission
1919 M Street, N.W.
Washington, D.C. 20554

Re: Request for Confidential Treatment
ET Docket No. 92-28; File No. PP-32

Dear Ms. Searcy:

On behalf of Motorola Satellite Communications, Inc. ("Motorola"), confidential treatment of the enclosed information and materials is requested pursuant to Sections 0.457(d) and 0.459 of the Commission's Rules and Regulations. See 47 C.F.R. §§ 0.457(d) & 0.459 (1991).

The materials and information included in the enclosed envelope are being submitted to the Commission in support of Motorola's pending request for a pioneer's preference in the above-referenced proceeding. It includes highly confidential, sensitive and company proprietary information concerning Motorola's IRIDIUM™ system. In particular, Motorola is submitting information concerning pending patent applications, preliminary results of experiments and field tests, a videotape of a voice simulation using the IRIDIUM system, and a computer diskette containing copyrighted software which simulates operation of intersatellite links.

All of this material and information constitutes trade secrets and commercial, financial or technical data which must be guarded from Motorola's competitors. See 47 C.F.R. § 0.457(d). Moreover, the enclosed materials and information clearly would be privileged, as a matter of law, as intellectual property and trade secrets if retained by Motorola. Id. Accordingly, the enclosed materials should be withheld from inspection by the public and not placed in the record of the above-referenced proceedings.

The enclosed materials have been submitted voluntarily by Motorola. Therefore, pursuant to Section 0.459(e) of the Commission's Rules and Regulations, if the Commission denies this request for confidential treatment, Motorola requests that the Commission return all of the enclosed materials and information without placing them in the public record. See 47 C.F.R. § 0.459(e).

Thank you for your prompt attention to this matter.

Respectfully submitted,

Philip L. Malet

Counsel for Motorola Satellite Communications, Inc.

Enclosure

cc: Dr. Thomas P. Stanley
William Torak
H. Franklin Wright
Robert Ungar
Counsel of Record